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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 226 days.

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H02H 9/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H02H 9/045*** (2013.01); ***H02H 9/008***
(2013.01); ***H02H 9/041*** (2013.01); ***H02H 9/042***
(2013.01); ***H02H 9/043*** (2013.01)

(58) **Field of Classification Search**
USPC 361/18, 30, 55
See application file for complete search history.

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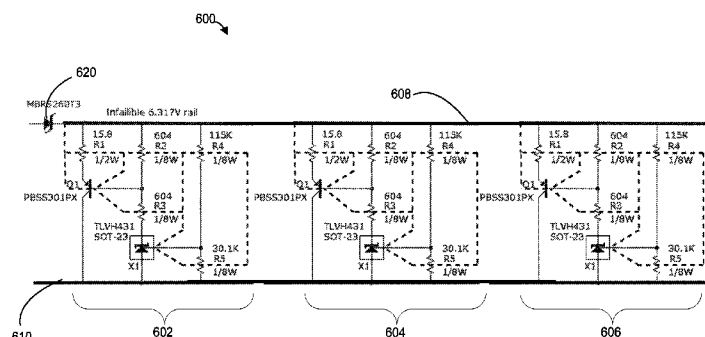
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(57) **ABSTRACT**

An intrinsically safe redundant regulator circuit includes a plurality of voltage limiting regulators between a regulated rail and a ground rail. Each of the plurality of voltage limiting regulators includes: (i) a shunt regulator component configured to clamp a voltage across the regulated rail and the ground rail to a safety clamp voltage value; and (ii) one or more components, where a property of each of the one or more components is selected to configure the safety clamp voltage value.

24 Claims, 6 Drawing Sheets



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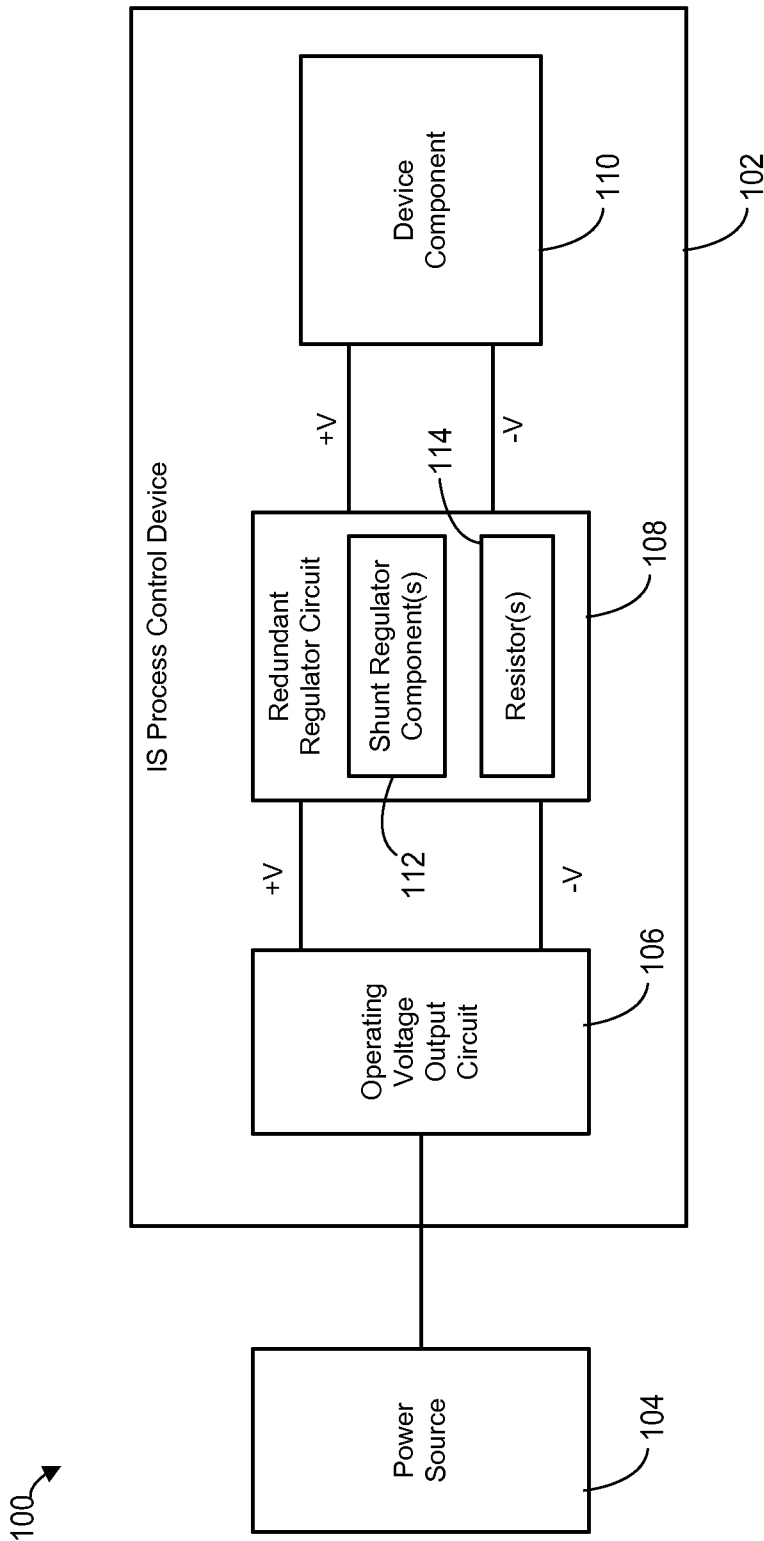


FIG. 1

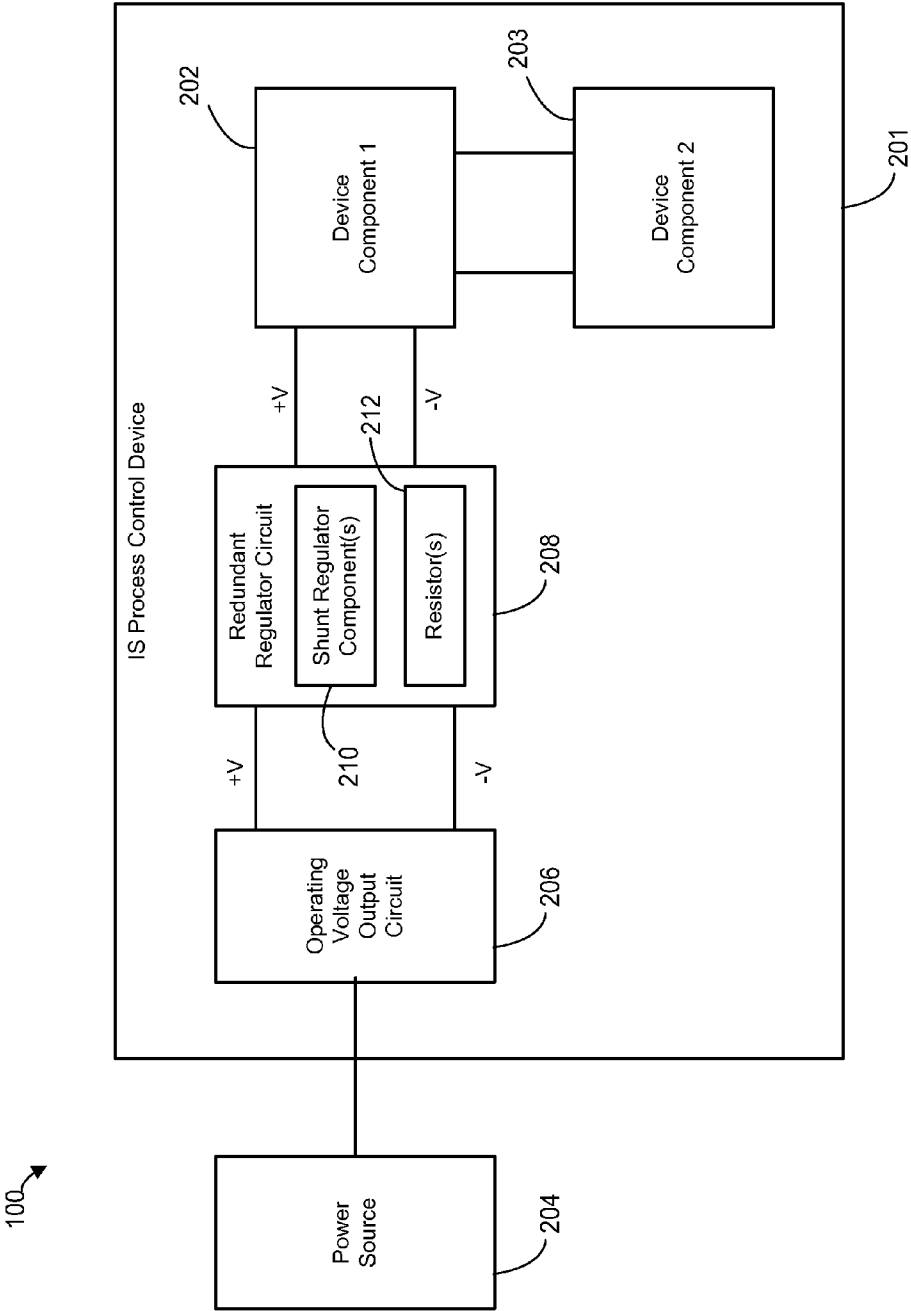


FIG. 2

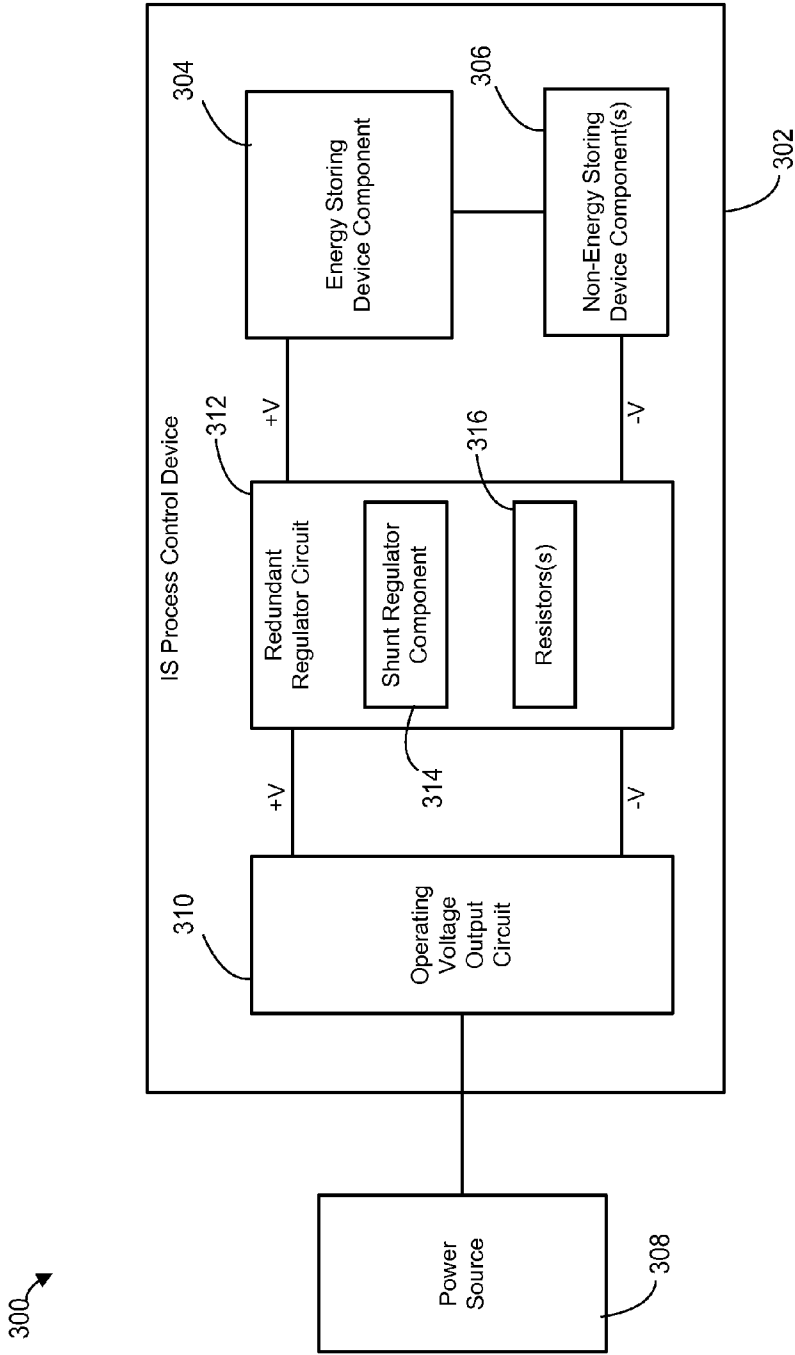
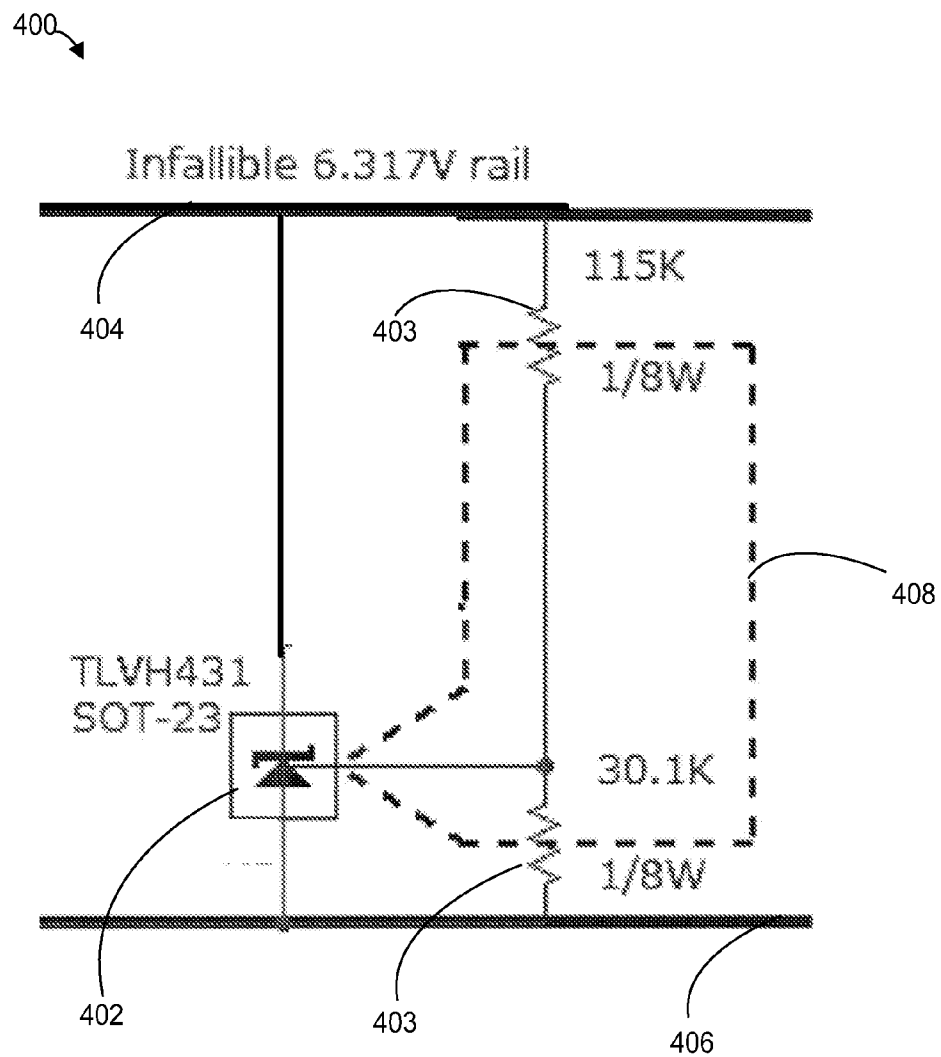


FIG. 3

**FIG. 4**

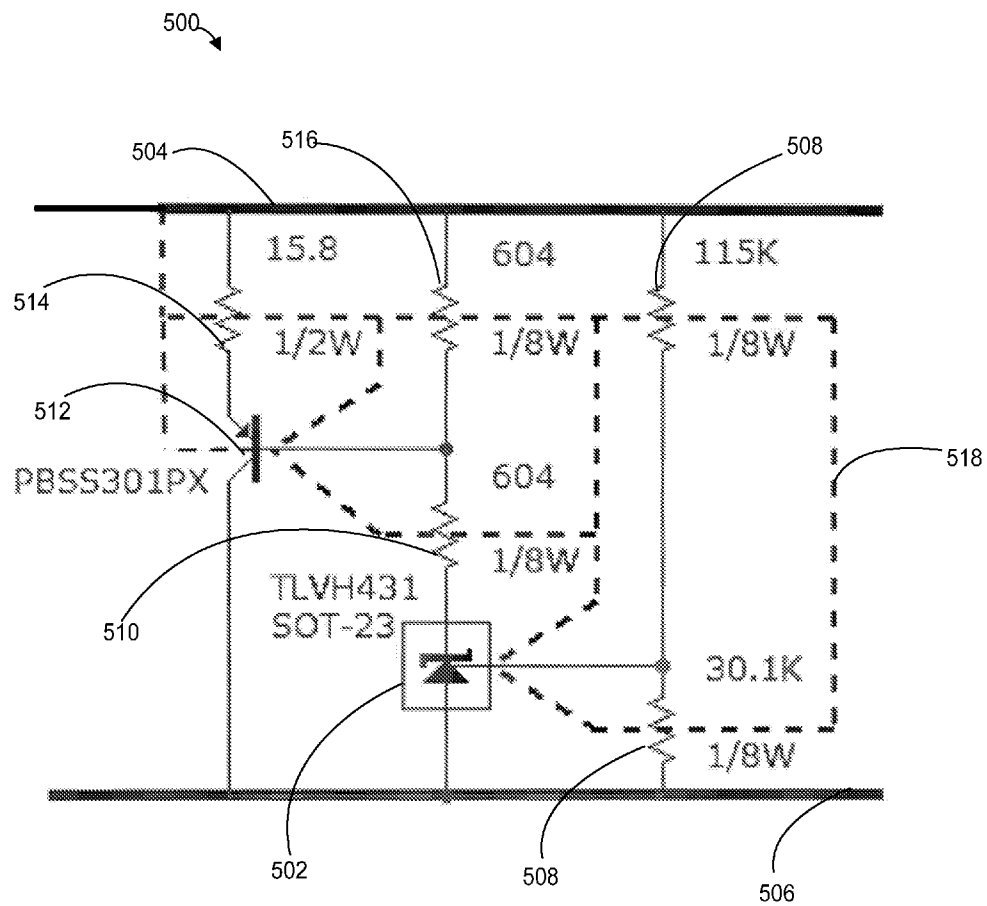


FIG. 5

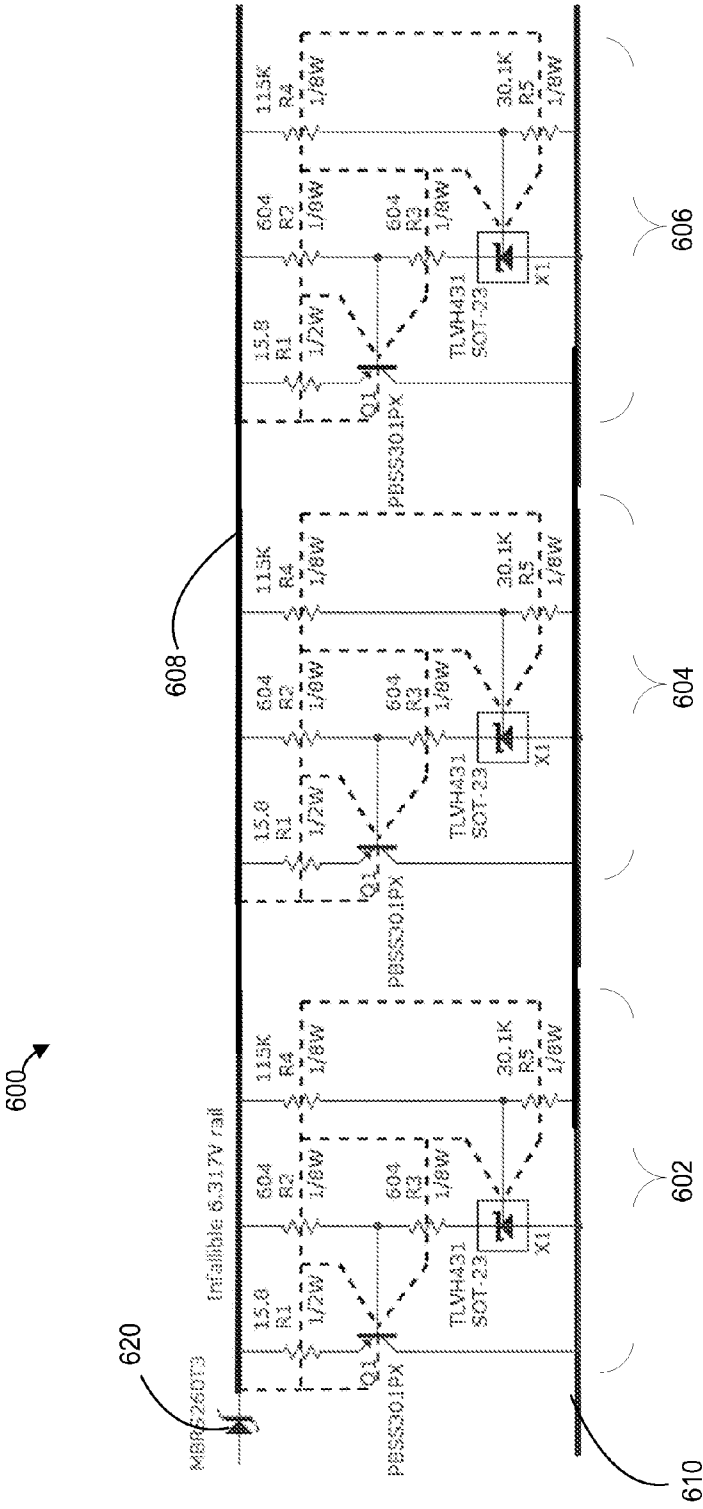


FIG. 6

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INTRINSICALLY SAFE VOLTAGE LIMITING SHUNT REGULATOR CIRCUIT

FIELD OF THE DISCLOSURE

The present disclosure is directed to intrinsically safe device circuitry and, more particularly, to an intrinsically safe voltage limiting shunt regulator circuit for devices in hazardous environments.

BACKGROUND

Some industrial processes, such as those in the petroleum industry, require devices to operate in hazardous atmospheres or other dangerous conditions. Such devices are often governed by a standard of “intrinsic safety”, such as the ISA-60079-11 standard, specifying certain conditions for devices in hazardous atmospheres. The conditions seek to either limit the amount of energy stored in device circuitry (e.g., by limiting voltages across capacitors or currents through inductors) or limit the discharge of accumulated energy (e.g., by restricting the spacing of components) such that a discharge of energy will not cause an ignition. In the case of the ISA-60079-11 standard, certain attributes of a device can be considered “infallible” if certain conditions, prescribed in the standard, are met. Generally, the circuitry of a device is considered “Intrinsically safe” if the circuitry remains safe with up to two “countable” faults.

Commonly, device circuits use Zener diodes as shunt voltage limiters to limit the voltage that could reach certain device components. However, while effective at such voltage limiting, Zener diodes must be operated at a voltage well below the Zener voltage to prevent leakage of current near the Zener voltage. In power sensitive applications (e.g., instruments powered by 4-20 mA signals), such current leakage is a significant concern. On the other hand, if a higher-voltage Zener diode is properly specified to prevent current leakage, the voltage limit increases, which may cause issues with respect to intrinsic safety.

SUMMARY

An intrinsically safe process control device comprises: a regulated rail, a ground rail, and a device component electrically coupled to both the regulated rail and the ground rail, wherein a voltage applied across the regulated rail and the ground rail causes energy to be stored in the device component. Further, the intrinsically safe process control device includes three or more voltage limiting regulators, each voltage limiting regulator disposed in parallel with the device component and each voltage limiting regulator including: a shunt regulator component configured to clamp the voltage across the regulated rail and the ground rail to a safety clamp voltage value, and one or more components, wherein a property of the one or more components is selected to configure the safety clamp voltage value.

An intrinsically safe redundant regulator circuit comprises: a plurality of voltage limiting regulators between a regulated rail and a ground rail. Each of the plurality of voltage limiting regulators includes: a shunt regulator component configured to clamp a voltage across the regulated rail and the ground rail to a safety clamp voltage value, and one or more components, wherein a property of the one or more components is selected to configure the safety clamp voltage value.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram that illustrates an example system including an intrinsically safe process control device implementing a redundant regulator circuit.

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FIG. 2 is a block diagram that illustrates another example system including an intrinsically safe process control device implementing multiple device components connected in parallel with a redundant regulator circuit.

FIG. 3 is a block diagram that illustrates yet another example system including an intrinsically safe process control device implementing both energy-storing and non-energy storing components connected in parallel with a redundant regulator circuit.

FIG. 4 illustrates an example circuit which can be implemented as part of one of the redundant regulator circuits illustrated in FIGS. 1-3.

FIG. 5 illustrates another example circuit which can be implemented as part of one of the redundant regulator circuits illustrated in FIGS. 1-3.

FIG. 6 illustrates an example redundant regulator circuit which can be implemented as the redundant regulator circuit illustrated in FIGS. 1-3.

DETAILED DESCRIPTION

The present disclosure is directed to a redundant regulator circuit for an intrinsically safe process control device such as a switch, solenoid, or transmitter, for example, and, specifically, to regulating voltages across intrinsically safe process control device components via the redundant regulator circuit. In particular, a redundant regulator circuit according to the present disclosure allows a process control device to operate at or near a safety clamp voltage of a shunt voltage limiter while, at the same time, qualifying as an “infallible” shunt voltage limiter.

Referring now to FIG. 1, an example system **100** constructed in accordance with one version of the present disclosure includes an intrinsically safe (IS) process control device **102** powered by a power source **104**. The IS process control device **102** may include a switch, transmitter, thermocouple, solenoid valve, etc. Further, the IS process control device **102** may be part of a manufacturing plant, oil or gas extraction structure, refinery, HVAC (heating, ventilation, and air conditioning) system, etc. in which the IS process control device **102** is exposed to a hazardous environment, such as an environment with hazardous gases, chemicals, vapors, dusts, fibers, etc.

The power source **104** provides power to various components, including to some circuits or components such as an operating voltage output circuit **106** that provide operating voltages for other circuits or components. For example, the power source **104** may provide power to the operating voltage output circuit **106**, which may output positive and negative voltages that are, in turn, applied to the rails of a redundant regulator circuit **108** and a device component **110**. The positive and negative voltages are denoted in FIG. 1 as +V and -V, respectively, but it is understood that a positive voltage may be applied to one of the rails of the redundant regulator circuit **108** and the device component **110** and the other of the rails may be grounded.

The power source **104** may include a power supply coupled to mains power, for example, where the mains power is coupled to the IS process control device **102** via an alternating current (AC) adapter, or the power source **104** may include a power supply coupled to battery power source (in which case it may be disposed inside the IS process control device **102**). The power source **104** may, in some cases, be electrically coupled to an operating voltage output circuit **106**, such as a power supply or regulator circuit, that may transform a power signal (e.g., 24V) to particular voltages (e.g., $\pm 3.3V$, $\pm 10V$),

where the particular voltages can be applied across rails of the redundant regulator circuit **108** and the device component **110**.

The IS process control device **102** may be qualified as intrinsically safe given certain associated entity parameters, in an implementation. With this type of entity qualification, the IS process control device **102** may qualify as intrinsically safe provided that other devices to which the IS process control device **102** is connected meet a corresponding set of entity parameters. A plant may then include multiple other devices attached to the IS process control device **102** and still maintain intrinsic safety, provided that the multiple other devices (e.g., in all considered combinations and fault scenarios) are compatible with the set of entity parameters corresponding to the IS process control device **102**.

By way of example, entity parameters corresponding to the IS process control device **102** may include a maximum allowed voltage, a maximum allowed current, an internal capacitance, an internal inductance, a maximum unprotected capacitance/inductance, an inductance/capacitance of inter-connecting wiring, or a maximum power. In one scenario, the entity parameters may include a maximum allowed voltage of 30V, a maximum allowed current value of 130 mA, and a maximum allowed power value of 1 W, for example.

The device component **110** may include an energy storing device component **110**, such as a capacitor or inductor or any device having internal capacitance or inductance. The voltage applied across the device component **110** may be regulated by the redundant regulator circuit **108** in parallel with the device component **110**, in some implementations. In this manner, the energy stored in the device component **110**, or a potential energy associated with an energy discharge, is limited, and the IS process control device **102** may be qualified as intrinsically safe (e.g., under the ISA-60079-11 standard). The redundant regulator circuit **108** may include one or more shunt regulator components **112**, such as low-voltage 3-terminal adjustable voltage references, and one or more resistors **114** configured such that the redundant regulator circuit is an “infallible” shunt voltage limiter, for example. Further details of the redundant regulator circuit **108** are discussed with reference to FIG. 4, FIG. 5, and FIG. 6.

Although the example system **100** includes one IS process control device **102**, one redundant regulator circuit **108**, one operating voltage output circuit **106**, and one device component **110**, a power source **104** may supply power to any number of IS process control devices with any number of redundant regulator circuits, device components, and operating voltage output circuits. For example, FIG. 2 illustrates an example system **200** including an IS process control device **201** implementing multiple device components **202** and **203**.

Similar to the system **100**, the system **200** includes a power source **204**, an operating voltage output circuit **206**, and a redundant regulator circuit **208**, where the redundant regulator circuit **208** includes one or more shunt regulator components **210** and one or more resistors **212**, in an implementation. However, in contrast to the system **100**, the system **200** includes two device components **202** and **203** operatively connected in parallel with the redundant regulator circuit **208**. The device components **202** and **203** may include two capacitors or two inductors, for example.

In general, an IS process control device may include any suitable number of energy storing components connected in parallel with a redundant regulator circuit. However, it is understood that an IS process control device may also include multiple redundant regulators. For example, an IS process control device may include two redundant regulator circuits, where each of the redundant regulator circuits is operatively

connected to a respective one of two device components. Further, multiple redundant regulator circuits may be operatively connected to multiple operating voltage output circuits allowing an IS process control device to supply differing voltages to device components.

FIG. 3 illustrates another example system **300** in which an IS process control device **302** includes an energy storing device component **304** and non-energy storing device components **306**. Again, the IS process control device **302** is powered by a power source **308** and includes an operating voltage output circuit **310**. However, in this example implementation, a redundant regulator circuit (e.g., including one or more shunt regulator components **314** and one or more resistors **316**) limits the voltage applied to both the energy storing device component **304** and non-energy storing device components **306**. The energy storing device component may include a capacitor or inductor and the non-energy storing device components **306** may include a variety of resistors. Generally speaking, an IS process control device may include any number and combination of energy-storing and non-energy storing device components in parallel with a redundant regulator circuit.

Referring now to FIG. 4, an example circuit **400**, which may be part of a redundant regulator circuit, includes a shunt regulator component **402** and one or more resistors **403**. In some implementations, a plurality of copies of the example circuit **400** may be connected in parallel to create an “infallible” voltage limiting shunt regulator. For example, three copies of the circuit **400** may be connected in parallel such that the resulting “redundant” combination limits voltage to a parallel connected device component even when two of the copies of the circuit **400** fail. An example redundant regulator circuit is further discussed with reference to FIG. 6.

The shunt regulator component **402** of the example circuit **400** is connected between a regulated rail **404** and a ground rail **406** and clamps a voltage applied across the regulated rail **404** and the ground rail **406** to a safety clamp voltage value, in an implementation. For example, the shunt regulator component **402** may be an integrated circuit (IC) configured as an adjustable voltage reference. Further, one or more components, such as the resistors **403** may set the safety clamp voltage value, in an implementation. The shunt regulator component **402** combined with the resistors **403** may clamp the voltage across the regulated rail **404** and the ground rail **406** to a magnitude of 6.317V. In this manner, the circuit **400** may limit the voltage applied to a device component, such as a capacitor connected in parallel with the circuit **400**, even when an applied voltage is greater than 6.317V. Although, the resistors **403** are illustrated in FIG. 4 as components whose resistance may be selected to configure the safety clamp voltage, it is understood that any suitable components or combination of components may be utilized to set the safety clamp voltage (e.g., by selecting properties of the components). For example, the resistance of a single resistor may be selected to configure the safety clamp voltage, in some embodiments.

As will be appreciated, the components of a redundant regulator circuit, such as the shunt regulator component **402** and the resistors **403**, may each have corresponding tolerance values. The resistors **403**, for example, may have associated resistance values (e.g., in Ohms) within a certain tolerance, such as a tolerance of five percent or one percent. In addition, sections of the redundant regulator circuit, such as redundant voltage limiting regulator sections, may each have a tolerance stackup based on the components in the respective sections. Thus the safety clamp voltage of each of a plurality of voltage limiting regulator sections may have a corresponding high

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value (at the top of the tolerance stackup), low value (at the bottom of the tolerance stackup), and nominal or average value (in the middle of the tolerance stackup).

In some implementations, the shunt regulator component **402** and the resistors **403** may be physically positioned on a circuit board so as to meet the infallible connection requirements of an intrinsically safe standard. For example, the dotted lines **408** may represent “countable” spacings of the shunt regulator component **402** with respect to the resistors **403**. Such countable spacings may ensure that failure of a space must be counted as a fault in the analysis of the circuit **400** for the double-fault tolerance required for intrinsic safety of the circuit **400**.

Although FIG. 4 illustrates the example circuit **400** that may be included as a redundant component in a redundant regulator circuit, entity parameters associated with certain IS process control devices may necessitate further power sharing, power limiting, or amplification components. If an entity parameter specifies a maximum power above the power rating of the shunt regulator component **402**, for example, a power sharing resistor may be included in the circuit **400** to prevent the shunt regulator component **402** from exceeding a corresponding power rating.

FIG. 5 illustrates an example circuit **500**, which may be part of a redundant regulator circuit, including power sharing/limiting and amplification components. In one implementation, the circuit **500** includes a shunt regulator component **502** capable of clamping a voltage across a regulated rail **504** and a ground rail **506** to a safety clamp voltage value, where the safety clamp voltage value is set by the resistances of one or more resistors **508**. Further, the power dissipated across the shunt regulator component **502** is limited by a power limiting resistor **510**. For example, a maximum power entity parameter of an IS process control device may exceed the power rating of the shunt regulator component **502**, and the resistance of the power limiting resistor **510** may be selected to limit the power dissipated across the shunt regulator component **502** to a value well below the power rating of the shunt regulator component **502**.

The example circuit **500** may also include a transistor component **512** and a corresponding power sharing resistor **514** to limit the power dissipated across the transistor component **512**. In some scenarios, the transistor component **512** may aid the clamping of voltages by amplifying the current drawn from the regulated rail **504**. For example, depending on the entity parameters associated with an IS process control device (e.g., in which the circuit **500** is installed), the transistor component **512** may or may not draw excess current away from the regulated rail **504** and prevent the accumulation of energy in device components, such as inductors. The example circuit **500** also includes a managing resistor **516** operatively connected to the transistor component **512**. The managing resistor **516** may selectively prevent activation of the transistor component **512** based on an applied voltage across the regulated rail **504** and the ground rail **506** and the current drawn by the shunt regulator component **502**. In this manner, the transistor component **512** may amplify current when the applied voltage is above a threshold while the managing resistor **516** ensures that the transistor component **512** is turned off when current shunting is not required, thereby preventing current leakage.

Similar to the example circuit **400**, the components of the circuit **500** may be physically spaced such that the circuit **500** adheres to countable spacing standards. Such spaces of device components are represented in FIG. 5 with one or more dotted lines **518**.

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In some implementations, a plurality of voltage limiting shunt regulator circuits, such as the circuit **400** or the circuit **500**, may be connected in parallel such that an “infallible” voltage-limiting assembly is formed. Such a circuit adheres to an intrinsically safe standard requiring safety with two or more circuit faults (e.g., “countable” faults of the ISA-60079-11 standard). FIG. 6 illustrates such a “triply redundant” regulator circuit **600** including three voltage limiting shunt regulators (voltage limiting regulators **602**, **604**, and **606**) similar to the circuit **500**. The triply redundant regulator circuit **600** may be implemented as one of the redundant regulator circuits **108**, **208**, or **312**, for example.

The triply redundant regulator circuit **600** may be considered infallible because two of the voltage limiting shunt regulators **602**, **604**, and **606** may fail while the other of the three voltage limiting shunt regulators **602**, **604**, and **606** may continue to safely clamp the voltage across a regulated rail **608** and a ground rail **610**. In one scenario, the voltage limiting regulators **602** and **604** may fail (e.g., due to component malfunction or damage) while the voltage limiting regulator **606** remains intact and functional.

Because each of the voltage limiting regulators may compete to clamp the voltage across the regulated rail **608** and the ground rail **610** if each is set to the same clamping voltage, the circuit **600** may have the potential to oscillate. Therefore, in some implementations, the safety clamp voltage of one of the voltage limiting shunt regulators **602**, **604**, and **606** may be set lower than the safety clamp voltage of the other two voltage limiting shunt regulators **602**, **604**, and **606**. For example, the highest safety clamp voltage value of a tolerance stackup corresponding to the voltage limiting shunt regulator **602** may be set lower than the lowest safety clamp voltage values of tolerance stackups corresponding to the voltage limiting shunt regulators **604** and **606**. In this manner, only one of the voltage limiting shunt regulators **602**, **604**, and **606** will clamp the voltage across the regulated rail **608** and the ground rail **610** during normal operation.

In addition to the components illustrated in FIG. 6, a redundant regulator circuit may include various other non-redundant components allowing the circuit to comply with intrinsically safe standards. For example, the circuit **600** may include a non-redundant power rectifier **620** to prevent energy storage in a case of reversed polarity of an input signal.

What is claimed is:

1. An intrinsically safe process control device comprising:
 - a regulated rail;
 - a ground rail;
 - a device component electrically coupled to both the regulated rail and the ground rail, wherein a voltage applied across the regulated rail and the ground rail causes energy to be stored in the device component; and
 - three or more voltage limiting regulators, each voltage limiting regulator disposed in parallel with the device component and each voltage limiting regulator including:
 - a shunt regulator component configured to clamp the voltage across the regulated rail and the ground rail to a safety clamp voltage value,
 - one or more components, wherein a property of the one or more components is selected to configure the safety clamp voltage value,
 - a transistor component configured to amplify a current from the regulated rail,
 - a power sharing resistor configured to limit the power dissipated across the transistor component, and
 - a managing resistor configured to prevent the transistor component from amplifying the current from the

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regulated rail when the voltage across the regulated rail and the ground rail is below a threshold.

2. The intrinsically safe process control device of claim 1, wherein each of the three or more voltage limiting regulators further includes:

a power limiting resistor configured to limit the power dissipated across the shunt regulator component.

3. The intrinsically safe process control device of claim 1, wherein the three or more voltage limiting regulators are compatible with a set of entity parameters.

4. The intrinsically safe process control device of claim 3, wherein resistance values of the power limiting resistor, the power sharing resistor, and the managing resistor are based on the set of entity parameters.

5. The intrinsically safe process control device of claim 1, wherein the one or more components includes a resistor and the property of the one or more components includes a resistance of the resistor.

6. The intrinsically safe process control device of claim 1, wherein the one or more components includes a plurality of resistors and the property of the one or more components includes a plurality of resistances each corresponding to a respective one of the plurality of resistors.

7. An intrinsically safe process control device comprising:

a regulated rail;

a ground rail;

a device component electrically coupled to both the regulated rail and the ground rail, wherein a voltage applied across the regulated rail and the ground rail causes energy to be stored in the device component; and

three or more voltage limiting regulators, each voltage limiting regulator disposed in parallel with the device component and each voltage limiting regulator including:

a shunt regulator component configured to clamp the voltage across the regulated rail and the ground rail to a safety clamp voltage value, and

one or more components, wherein a property of the one or more components is selected to configure the safety clamp voltage value,

wherein the safety clamp voltage value corresponding to one of the three or more voltage limiting regulators is lower in magnitude than the safety clamp voltage value corresponding to the remaining of the three or more voltage limiting regulators, and

wherein a highest clamp voltage value of a tolerance stackup corresponding to one of the three or more voltage limiting regulators is lower than the lowest clamp voltage value of a tolerance stackup corresponding to the remaining of the three or more voltage limiting regulators.

8. The intrinsically safe process control device of claim 7, wherein each of the three or more voltage limiting regulators further includes:

a power limiting resistor configured to limit the power dissipated across the shunt regulator component.

9. The intrinsically safe process control device of claim 7, wherein the three or more voltage limiting regulators are compatible with a set of entity parameters.

10. The intrinsically safe process control device of claim 9, wherein resistance values of the power limiting resistor, the power sharing resistor, and the managing resistor are based on the set of entity parameters.

11. The intrinsically safe process control device of claim 7, wherein the one or more components includes a resistor and the property of the one or more components includes a resistance of the resistor.

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12. The intrinsically safe process control device of claim 7, wherein the one or more components includes a plurality of resistors and the property of the one or more components includes a plurality of resistances each corresponding to a respective one of the plurality of resistors.

13. An intrinsically safe redundant regulator circuit comprising:

a plurality of voltage limiting regulators between a regulated rail and a ground rail, wherein each of the plurality of voltage limiting regulators includes:

a shunt regulator component configured to clamp a voltage across the regulated rail and the ground rail to a safety clamp voltage value,

one or more components, wherein a property of the one or more components is selected to configure the safety clamp voltage value,

a transistor component configured to amplify a current from the regulated rail,

a power sharing resistor configured to limit the power dissipated across the transistor component, and

a managing resistor configured to prevent the transistor component from amplifying the current from the regulated rail when the voltage across the regulated rail and the ground rail is below a threshold.

14. The intrinsically safe redundant regulator circuit of claim 13, wherein each of the plurality of voltage limiting regulators further includes:

a power limiting resistor configured to limit the power dissipated across the shunt regulator component.

15. The intrinsically safe redundant regulator circuit of claim 13, wherein the plurality of voltage limiting regulators are configured according to a set of entity parameters.

16. The intrinsically safe redundant regulator circuit of claim 15, wherein resistance values of the power limiting resistor, the power sharing resistor, and the managing resistor are based on the set of entity parameters.

17. The intrinsically safe redundant regulator circuit of claim 13, wherein the plurality of voltage limiting regulators includes at least three voltage limiting regulators.

18. The intrinsically safe redundant regulator circuit of claim 13, wherein the one or more components includes a resistor and the property of the one or more components includes a resistance of the resistor.

19. An intrinsically safe redundant regulator circuit comprising:

a plurality of voltage limiting regulators between a regulated rail and a ground rail, wherein each of the plurality of voltage limiting regulators includes:

a shunt regulator component configured to clamp a voltage across the regulated rail and the ground rail to a safety clamp voltage value, and

one or more components, wherein a property of the one or more components is selected to configure the safety clamp voltage value,

wherein the safety clamp voltage value corresponding to one of the plurality of voltage limiting regulators is lower in magnitude than the safety clamp voltage value corresponding to the remaining of the plurality of voltage limiting regulators, and

wherein a highest clamp voltage value of a tolerance stackup corresponding to one of the plurality of voltage limiting regulators is lower than a lowest clamp voltage value of a tolerance stackup corresponding to the remaining of the plurality of voltage limiting regulators.

20. The intrinsically safe redundant regulator circuit of claim 19, wherein each of the plurality of voltage limiting regulators further includes:

a power limiting resistor configured to limit the power dissipated across the shunt regulator component.

21. The intrinsically safe redundant regulator circuit of claim **19**, wherein the plurality of voltage limiting regulators are configured according to a set of entity parameters. 5

22. The intrinsically safe redundant regulator circuit of claim **21**, wherein resistance values of the power limiting resistor, the power sharing resistor, and the managing resistor are based on the set of entity parameters.

23. The intrinsically safe redundant regulator circuit of 10 claim **19**, wherein the plurality of voltage limiting regulators includes at least three voltage limiting regulators.

24. The intrinsically safe redundant regulator circuit of claim **19**, wherein the one or more components includes a resistor and the property of the one or more components 15 includes a resistance of the resistor.

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